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LEARNING APTITUDE, ERROR TOLERANCE, AND ACHIEVEMENT LEVEL AS FACTORS OF PERFORMANCE IN A VISUAL-TRACKING TASK

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This paper presents results from an investigation of learning effects and operator tolerance for error as confounding factors in measuring visual tracking skill. Subjects were 20 students and 9 attritees from Army helicopter pilot training. Results supported an hypothesis that existing test procedures allowed for the confounding of learning and changes in tolerance for error with baseline estimates of operator tracking skill. Modified testing and statistical procedures are recommended. Information on individual differences

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in tolerance for error are seen as a potentially useful predictor of success in pilot training.

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FOREWORD

The research presented in this report was conducted under the Aircrew Performance Project in the Flight Training and Aviator Selection Technical Area of the Fort Rucker Field Unit of the Army Research Institute for the Behavioral and Social Sciences (ARI). The Aircrew Performance Project provides aircrew training research for Army Aviation and directly supports training and personnel research needs of the US Army Aviation Center, Fort Rucker, AL. One program of research is the investigation of tests of human performance to measure information processing, psychomotor, and time-sharing skills as predictors of success in training and as Army aviators. ARI Technical Report 412 is the first publication from this program of research.

Related, ongoing programs of research in the Flight Training and Aviator Selection Area include revision of the existing paper and pencil Flight Aptitude Selection Test (FAST) and the development of tests and methods to classify aviator trainees for mission specialities in advanced undergraduate training. The human performance testing research is also related to the job-sample testing application of flight simulators in the Performance-Based Aviation Applicant Selection System program in the Flight Simulation Area.

The results of the human performance and related test research are expected to yield a battery of selection and classification tests which will improve the validity of the aviator selection and classification processes. It is also anticipated that selected human performance tests may be used as blocking variables or co-variates to improve the statistical power and efficiency of ARI aviator training experiments. Future research with the human performance tests will include determination of major factors in the research battery, the development of selection and classification criteria, and the assessment of predictive validities for each of the applications.

The present research was conducted by personnel of the Flight Training and Aviator Selection Area as an in-house project under Army Project 2Q763743A772. An earlier version of this report has been printed in the 1978 Proceedings of the Military Testing Association.

Joseph Zeidner

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LEARNING APTITUDE, ERROR TOLERANCE, AND ACHIEVEMENT LEVEL AS FACTORS OF PERFORMANCE IN A VISUAL-TRACKING TASK

BRIEF

Requirement:

The US Army Aviation Center has requested that the US Army Research Institute (ARI) develop testing methods to screen potential Initial Entry Rotary Wing (IERW) Course failures, resignations, and poor learners not screened by the existing paper and pencil Flight Aptitude Selection Test (FAST). Data from these testing methods should also support the assignment of students in IERW to mission-tracks for advanced IERW training.

Procedure:

The purpose of this investigation was to evaluate possible sources of confounding in the results of a psychomotor test of ability to control an unstable system prior to a validation study. Recommended changes in testing and scoring procedures were derived from a review of related literature. To test the proposed changes, the revised test was administered to nine individuals who had recently resigned or been eliminated from warrant officer or helicopter pilot training and 20 of their contemporaries who were still in helicopter pilot training at the US Army Aviation Center.

Findings:

The revised testing and scoring procedures were found to result in better information about categories of subject performance than existing procedures.

Application of Findings:

The findings of this study were used as justification for more testing time with the psychomotor test in planning the validation study. An additional product was a computer program, in FORTRAN, for scoring individual performance data from the psychomotor test.

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INTRODUCTION

The Army Research Institute Field Unit at the Army Aviation Center is conducting aviator trainee selection research on job-sample, psychomotor, information processing, and time-sharing tests to improve the methods of selecting applicants for Army helicopter pilot training. This paper presents preliminary results from an investigation of methods to improve the measurement of visual tracking and time-sharing skill as a part of that research. In this section, the test is described, some sources of confounding are considered and methods to overcome the confounding are presented. Following the introduction, procedures are described for collecting data to test selected hypotheses about confounding. Then, the results of the data collection are presented and the discussion section focuses on the prospects for employing data from the visual tracking tests in time-sharing and aviator trainee selection research.

Visual Tracking Test

The visual tracking test used in the current research was designed to measure an individual's ability to control an unstable system. The test device is a single axis, compensatory visual tracking task described in Pew, Rollins, Adams and Gray (1977). The operator's task is to try to maintain a light spot in the center of a horizontal display using lateral movements of a finger operated joy-stick.

The test difficulty is controlled by the system time constant in the periodic processing of the control stick signal. The system time constant is a weighting function which determines the rate of change of light spot location in relation to control stick movements. The system time constant operates as a divisor so that the size of the constant is inversely related to test difficulty. The test device periodically samples the control stick signal and computes the location of the light spot as a weighted function of the present control input and a residual component from previous control signals added to the present light spot location value. The residual component is correlated with the operator's previous control behaviors and greatly increases the difficulty of learning effective control of the light spot.

The tracking test device can be operated in two difficulty modes: critical and fixed difficulty tracking. The fixed difficulty, or fixed tracking mode was designed primarily for time-sharing applications. In this mode, the tester fixes the time constant at a given value and the operator performs for a fixed period of time. The measure of skill in fixed tracking mode is the total absolute deviation of the light spot from the center of the display, averaged across the time of performance.

The critical difficulty, or critical tracking mode is used to estimate the operator's effective time delay. The effective time delay represents the minimum operator response time for the detection and correction of errors in continuous control tasks and is used as a parameter in human information processing and optimum control theory models of operator behavior. Operationally, the effective time delay is an index of the amount of time required for the operator to detect an error and to convert information about that error into a precise control movement. Estimates of the effective time delay from the critical tracking mode are employed as the value of the fixed time constant in the fixed tracking mode.

To measure the effective time delay in critical tracking mode, the test device progressively increases test difficulty as a function of time in the performance. Difficulty is progressively increased by systematically reducing the size of the time constant as a function of time in performance. As the time constant grows smaller, the rate of change in light spot location per unit time increases. Eventually, the rate of change in light spot location becomes so rapid that the operator is unable to maintain effective control, the location exceeds the limits of the display, and the performance ends. The measure of skill is the estimated effective time delay which is the size of the system time constant at the end of the performance. This investigation was designed to evaluate possible confounding effects in the measurement of critical tracking skill, i.e., measurement of the effective time delay.

Confounding Effects

A review of recent research with the present test (Pew et al., 1977) and two similar visual tracking tests (Damos, 1977; Gopher & North, 1974; North, 1977; North, Harris & Owens, 1978) suggested that the testing procedures had resulted in a confounding of other performance factors with the measurement of visual tracking skill. Pew et al. defended their procedures with evidence of test-retest reliability (Rose, 1974).

In the research with similar tests there was evidence that confounding effects had degraded the validity of the visual tracking data to estimate time-sharing capacity and would probably degrade the validity of these measures in aviator selection decisions. Gopher et al. (1974) and North (1977) observed improvements in time-sharing performance as contrasted with predictions from single-task performance. Gopher et al. offered three hypotheses which might account for these discrepancies: (a) Use of adaptive logic did not accurately estimate single-task tracking skill; (b) There was an improvement of single-task tracking skill as a function of practice in the time-sharing test; and (c) There is an independent time-sharing skill which is learned only in practice with time-sharing tests. At the conclusion of his report, North (1977) suggested that "isolation of improvement factors is an important direction for further research" (p. 92).

Two investigations addressed the question of confounding sources. In a transfer of training experiment, Damos (1977) found weak evidence of improvement of both single-task and time-sharing skill as a function of practice in multiple-task performance. Indications of confounding effects in the Damos (1977) data were: (a) operator unreliability as evidenced by heterogeniety of variance; and (b) failure of 16.7% of the subjects, 8 of 48, to achieve minimum criterion in subsequent time-sharing practice.

Although not specifically addressed by the authors, some difficulties with the use of adaptive logic to determine test difficulty were apparent in the investigation of test-retest reliability by North et al. (1978). The adaptive logic was used to establish tracking test difficulty in the first part of two daily testing sessions. After fixing the level of difficulty, the mean root-mean-square (RMS) tracking error was computed as the baseline for feedback on tracking performance in the time-sharing tests. Table 1 is a summary of correlations among the tracking task difficulty and RMS tracking error scores across the two daily sessions and two days of testing.

It is apparent from the data in Table 1 that test difficulty correlates negatively with dual-task RMS tracking error. This has potentially serious consequences in aviator trainee selection research because individuals who invest greater effort, and thus achieve higher levels of difficulty, would have greater difficulty demonstrating higher levels of time-sharing capacity. Conversely, individuals with low effort in the test difficulty phase would more easily exhibit greater capacity in time-sharing. In addition, Table 1 shows a significant decrease of correlation between single-task and time-sharing RMS error between the first and second days of testing. Since the high test-retest correlation ($\underline{r}$ = .90) between test difficulty across the two days of testing shows that the subjects were consistent in the amount of effort invested in the measurement of test difficulty, there were differential changes among individual RMS error performances as a function of changes in single-task performance. This is supported by the low reliability in single task RMS performance ($\underline{r}$s = .01 & .34) and the moderate test-retest reliabilities of RMS dual-task performance ($\underline{r}$s = .49 & .69).

Therefore, the available evidence suggests that procedures for measuring task difficulty allow for two major sources of confounding: (a) failure to train to asymptote before measuring single-task achievement, and (b) using current performance error as a criterion for adaptive adjustments of test difficulty. The first source of confounding could apparently be removed by training to asymptote or by developing a statistical model which accurately predicts asymptotic level of achievement from selected observations of learning performance. To remove the second source of confounding it was necessary to explain how differences in individual goals, effort, motivation and the like might interact with

Table 1

SELECTED INTERCORRELATIONS AND TEST-RETEST CORRELATIONS AMONG MEASURES OF TRACKING TASK DIFFICULTY, SINGLE- AND DUAL- TASK RMS TRACKING ERROR[a]

	Day 1 RMS Dual-Task	Day 2 RMS Dual-Task	Test/ Retest
Session A			
Task Difficulty	-.53[b]	-.43[b]	.90[b]
RMS Single-Task	.52[c]	.13[c]	.01
RMS Dual-Task			.49
Session B			
RMS Single-Task	.59[c]	.10[c]	.34
RMS Dual-Task			.69

[a]North et al., (1978), p. 16

[b]Probability is less than .05 that the absolute value of any correlation greater than .388 is greater than zero; $t(.388) = 2.064$, $df = 24$.

[c]Probability is less than .05 that the differences between each pair of Day 1 minus Day 2 values is greater than zero; $Z(.52) - Z(.13) = 2.14$ (Fisher's r to Z transform).

single-task difficulty to obscure level of achievement and then to provide a means of measuring the degree of the interaction in an individual's tracking test data. As suggested in the following discussion, an adequate solution to the degree of effort problem is necessary to improve the validity of forced as well as adaptive difficulty testing paradigms.

Tolerance for Error

In a review of human performance limitations in visual tracking tasks, Poulton (1969) uses "tolerance for error" to explain how individual effort interacts with measures of tracking task ability. When first introduced to a relatively easy task, i.e., one with a single dimension or a simple control system, Poulton says that initially the operator will be challenged and interested in the task giving considerable attention and effort to task performance. Poulton continues:

> But...[the operator] soon discovers what he can and cannot achieve, and settles down to give what he considers to be an adequate performance. A small error comes to be tolerated, and effort is directed only at preventing or correcting large errors (Helson, 1949, p. 495). The task becomes analogous to a vigilance task, and fails to occupy the man's full channel capacity or attention.
>
> At this stage the level of performance can be improved by presenting the man with a challenge....knowledge of results can reduce the size of the error which the man will tolerate, and so raise the standard of his performance.
>
> Unfortunately, a change in experimental conditions that makes the task harder may also present a challenge to the man. This means that the poorer performance which is to be expected as a result of increased difficulty of the task may be partly offset by the challenge effect. Tracking in one dimension is thus not as sensitive to changes in experimental conditions as are tasks which occupy the man's channel capacity more fully... (1969, pp. 312-313)

Poulton's analysis indicates that the operator may decide to limit control effort to the prevention or correction of large errors. In his view, this decision converts the task from pure tracking to vigilance performance conditions. Success in vigilance performance is determined by error detection, the degree of error to be tolerated, and skill in error correction. Error detection will reflect differences in operator vigilance strategy. To prevent large errors, the operator maintains a higher level of attention or effort to anticipate and respond to performance conditions which, if uncorrected, would result in unacceptably large errors. On the other hand, when the operator strategy is to correct large errors, the operator responds only if he has detected the occurrence of deviations which have exceeded his acceptable tolerance limit.

An operator shift from pure tracking to one of the vigilance performance strategies would explain how the adaptive logic in the Gopher et al. (1974) testing paradigm allowed subjects to exhibit differential improvements over baseline predictions in dual-task performance. The adaptive logic in the Gopher et al. paradigm was expressed as a function of target error measured as deviation from center of the visual display. When error was consistently less than 10% of display length, task difficulty was progressively increased. If error consistently exceeded the 10% limit, task difficulty was reduced. Task difficulty stablized when the errors were distributed about equally above and below the limiting value. Given stable or increasing levels of skill, an operator decision to tolerate greater error would cause an increase in the observed deviations which would, in turn, cause a decrease in the existing estimate of task difficulty. The amount of decrease would be a direct function of the increase in error tolerance. In subsequent performances the operator would be able to achieve correspondingly less average error than predicted for higher levels of difficulty because the observed estimate of task difficulty underestimated the true level of skill.

Although the tolerance for error process invalidates existing procedures to estimate task difficulty with an adaptive logic approach, it must also be accounted for in a forced difficulty paradigm, e.g., Pew et al. (1977). Poulton's analysis implies that a decision to limit control effort represents the end of a learning phase in skill acquisition. However, the operator might become bored, fatigued, or otherwise disinclined to maintain effort to learn or perform before completely mastering the task. Estimates of task difficulty before a decision to switch from tracking to vigilance performance would thus underestimate the true asymptotic level of achievement. As an aside, there would be some training management value in knowing the extent of any skill improvement which might occur as a function of practice after the switch to the vigilance mode of performance.

The concept of tolerance for error and the corresponding switch from tracking to vigilance performance strategies has definite measurable implications. Suppose performance is represented as a sequence of observations of a measure of skill from repeated trials across some extended period of time. If greater effort in the learning phase corresponds to improvement of skill level and a constant or perhaps decreasing level of performance variability, data from the repeated observations should exhibit a definite trend of improvement of level of skill. An increased level of error after the shift to the vigilance phase should be observed as a discontinuity of either mean or variability of performance. In the vigilance phase, the observations should represent random samples from a distribution with mean and variance determined by the degree of error tolerance and the particular vigilance performance strategy. Statistical methods for estimating parameters from repeated observations will be considered after a brief summarization of the implication that an operator may attempt to minimize effort rather than maximize performance.

To summarize the implications of Poulton's concept of tolerance for error, it was hypothesized that (a) differences in operator goals, attitudes and the like would be represented in different performance strategies, (b) these strategies could be operationally defined on a scale of performance effort, and (c) different strategies and tolerances for error would lead to measurable differences in patterns of performance associated with the corresponding level of effort. The two extremes of the scale of effort would be performance maximization at the high effort end and effort minimization at the low end. Figure 1 depicts a schematic layout of the scale of effort concept and the ordering of performance strategies which were logically differentiated in the preceeding analysis of the tolerance for error concept.

Mean Square Successive Differences

Standard statistical methods from the area of time-series data analysis provided the analytic tools needed to evaluate both trend and variability components in a sequence of tracking performance observations. Since these methods are commonly used in engineering and economic analyses, some of them may not be familiar to the psychologist. An understanding of mean square successive differences (MSSD) is crucial to the interpretation of the results of this investigation. Therefore, MSSD is described in limited detail here. Readers interested in greater detail should refer to the technical sources and those already familiar with MSSD may skip to the next section without any loss of continuity.

Mean square successive differences is a measure of variability of performance based on the order of the observations as the origin. As a measure of trend strength in a set of time-series data, e.g., repeated measures, MSSD derives its meaning from the fact that pairs of adjacent observations will be more highly correlated than will be pairs of more widely separated values. This sequential dependency of the observations on their order means that with a trend present in the data, differences between pairs of adjacent observations will be smaller than when the data is from a random sample. The variance is the average variability of the observations with the mean as the origin. Therefore, a comparison of the variance with MSSD will be an index of trend strength. When there is a linear or polynomial trend in the data, the MSSD will be small relative to the variance as illustrated in Figure 2. Without a stable trend, MSSD will approach the variance as a measure of variability. (See Brownlee, 1965, pp. 221-223 for a proof and more detail on computational methods.)

Standard methods are used to transform the ratio of MSSD to the variance into a standard normal deviate, i.e., a z-score (Brownlee, 1965). As a standard normal deviate this transformed ratio can be employed to

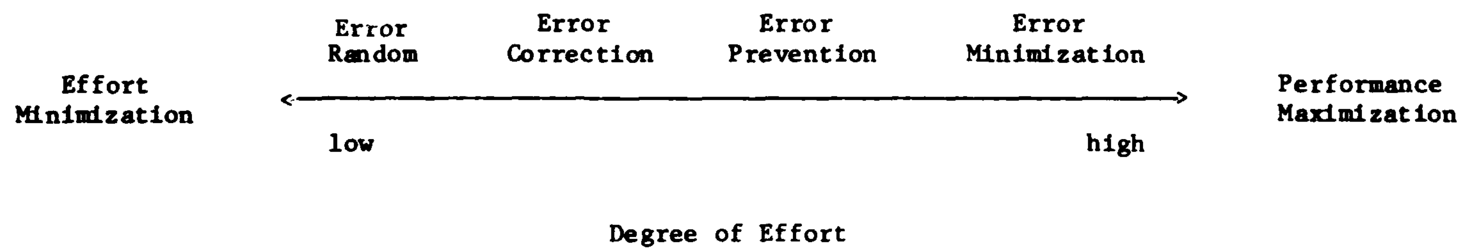

Figure 1. Schematic Depiction of Tolerance for Error as a Function of Degree of Effort

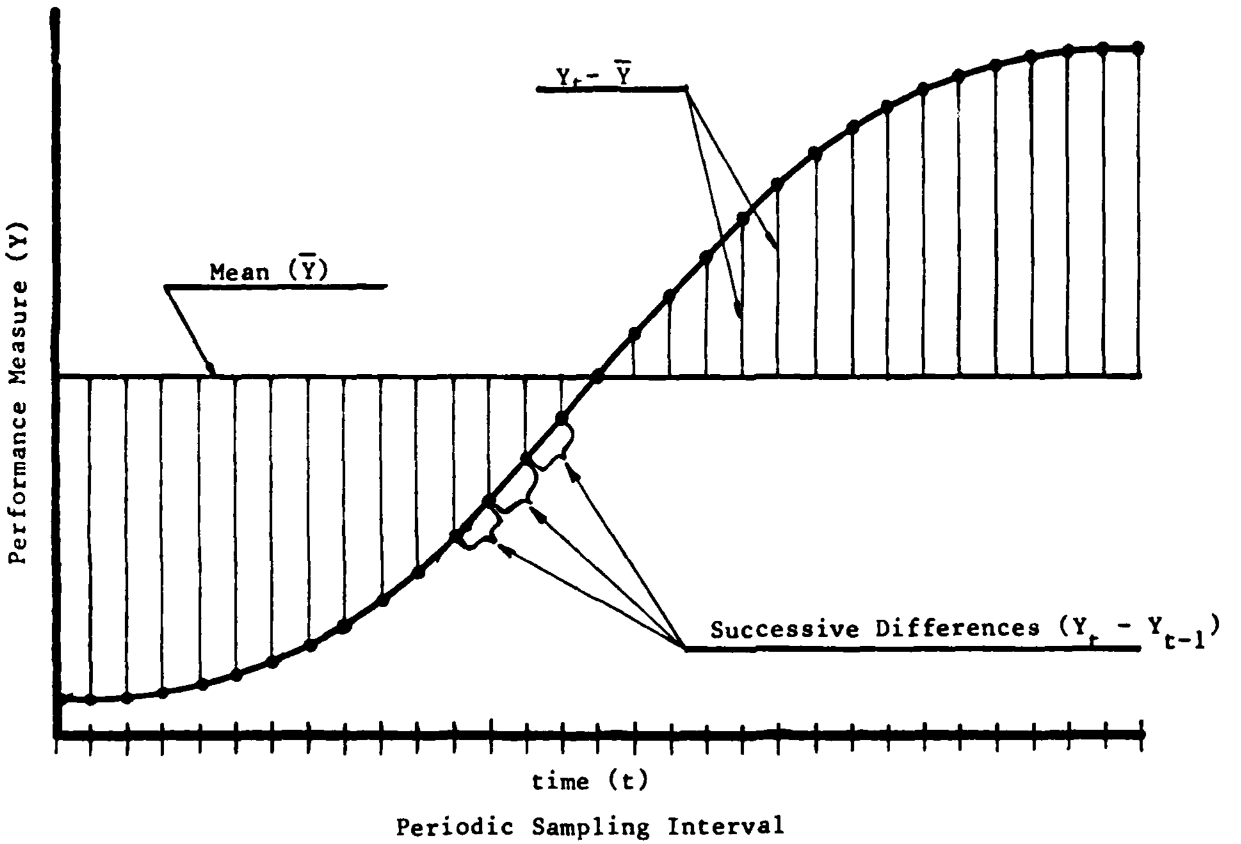

Figure 2: Depiction of relationship between successive differences and deviations from the mean in a set of time series data with a polynomial trend.

determine the departure of the data from randomness in the conventional statistical way. That is, the investigator posits an alpha probability and accepts or rejects the null hypothesis of no trend as the obtained *z*-score indicates. Brownlee reports that other investigators have shown that the *z*-score transform is acceptable with as few as ten observations and tables exist for use with as few as four observations. Unfortunately, these tables are not generally available and the occasional user may find it difficult to obtain copies (see Hart, 1942, for tables).

Research Hypothesis

The preceding analyses suggested that (a) the concept of tolerance for error would associate changes in performance effort and differences in such attitudinal variables as operator goals, motivation or interest in the task with differences in patterns of performance, particularly variability of performance, over time; and, (b) the MSSD measure would discriminate the presence or absence of trends in time series data. Suppose that two groups of subjects were selected on the basis of presumed differences in attitude, that if present, these attitudinal differences would result in differences in performance effort, and that members of these groups were given a series of trials with the Pew et al. (1977) visual tracking test in critical tracking mode. Finally, if the MSSD measure was then used to categorize performance by the members of each group into subgroups of random or non-random, analysis of trends or variability in the data for the resulting two by two contingency table should reveal an interaction of attitudinal group with type of performance across blocks of performance trials. The trials would be blocked to provide means and standard deviations to estimate the "local" level of achievement and variability of performance. The following data collection and analysis methods were employed to test this hypothesis of a triple interaction.

METHODS

Subjects

Data for this investigation were obtained from the records of 29 individuals who had participated in a comorehensive selection testing research program. Nine of the individuals had recently resigned or been eliminated from warrant officer or helicopter pilot training and 20 of their contemporaries were still in the Army warrant officer helicopter pilot training program at th US Army Aviation Center, Fort Rucker, AL.

Test Apparatus

A model 620 Visual Tracking Analyzer manufactured by Bolt, Beranek and Newman, Cambridge, MA, was used to administer the visual tracking test. The model 620 is capable of testing in either fixed or critical tracking mode but this investigation was limited to critical tracking data. The light spot is displayed on a horizontal unit 20 by 7.5 by 10 cm which contains a horizontal line of 64 light emitting diodes, each spaced 2.54 mm apart. The display unit is connected to a master control unit by a 15 foot wire cable with connectors at each end. The master control unit provides basic electronic circuitry, power supply, and the tester's unit. The tester's unit provides controls to (a) select the mode of tracking operation, (b) set the number of trials per testing block, (c) start a block of test trials, (d) enable the start of each test trial, (e) reject any unsuitable trial performance, and (f) conduct a standard system checkout to verify each of the system functions and displays and provide demonstrations of key features to each subject. Displays on the tester's unit provide status information about the state of the system, number of the current trial in a block, and the score for both the most recently completed trial and the current block average.

The subject controls the location of the light spot with lateral movements of a spring-loaded, finger operated joy-stick. One degree of stick deflection corresponds to a movement of 2.36 mm on the visual display. The control stick is mounted on a metal box 11.2 by 17.5 by 5 cm and it is connected to the visual display unit by a 6 foot wire cable with connectors at each end. The subject's control unit also contains a calibration thumb wheel and two trial start buttons, one button on either side of the control stick.

To measure the effective time delay, the test apparatus is operated in the critical tracking mode. The value of the system time constant at the end of a trial is the index of the subject's effective time delay for that trial. At the start of a trial the system automatically set the time constant at 500 milliseconds (ms). As the trial progresses the time constant is reduced at the rate of 10 ms per second until the light spot has deviated 2.5 cm from the center of the display and at the rate of 2.5 ms per second after the light spot has exceeded the 2.5 cm limit. As the size of the time constant decreases, the rate of movement on the display increases until the subject is unable to maintain the light spot location within the limits of the display. When the light spot location exceeds the limits of the display, the system stops the trial, displays the trial score and the current value of the block mean effective time delay on the tester's display, and signals an end of trial on the tester's status display. The tester must then record the trial score if it is desired and enable a new trial. The system is designed so that an attempt to enable a new trial at the end of a block will result in an end of block signal on the tester's status display.

Procedure

Subjects reported to a standard testing location according to a prescribed week long testing schedule. This testing schedule was worked out to provide continuity of testing over a five day period and to minimize the test activity interference with routine training. The second day of testing was used to give 40 trials of the critical tracking test in 4 blocks of 10 trials. The tester set the system to the system checkout/demonstration mode. When the subject reported for testing, he/she was seated at a table with the finger operated control stick. The tester then read through the following instructions:

> In this test your job is to control the movements of this light spot [tester points to light spot on visual display] with the control stick in front of you. Take hold of the stick in a comfortable position and move it right and left. Notice that the control moves the light spot back and forth on the display. Later, when you start the test, the light spot will move randomly right or left on the display from time to time. As a test progresses, the time between these random movements gets shorter and shorter and it gets harder and harder to control the position of the light spot. Finally, the light spot goes out of control, off the end of the display, and the system will freeze the light spot at the end of the display. Your score will be the time between the random movements when the light spot is frozen.
>
> (Tester note: Set the system in CRITICAL MODE.)
>
> Notice that the light spot is now frozen at the end of the display. Move the control stick and notice that the light spot does not move. When this happens that means the end of the test and I will read your score to you. To start a test you will find two buttons next to the control stick marked "START". After I say "Ready" you may push either button to start the test. When you release the button, the light spot will automatically move to the center of the display and the test will start. (Tester demonstrates.) Do you have any questions?
>
> You will repeat the test 40 times in the next hour. After each trial I will read your score to you. The smaller your score the better your performance. Your objective should be to get the smallest possible score in the fewest trials. To get a small score it is very important to keep the light spot as near the center of the display as possible. Do you have any questions on scoring?

Each trial was followed by 15 seconds rest and there was a 2 minute rest period after each block of 10 trials. At the end of each trial, the tester recorded the trial score, reported it orally to the subject, timed the rest interval, enabled the system for the next trial or block, and at the end of the rest time, announced "Ready" to signal the subject to start the next trial.

The subject participated in fixed difficulty tracking on the third and fourth days of testing before receiving a final test in critical difficulty tracking. On the third day the subject performed fixed difficulty tracking to establish levels of skill for the time-sharing test given on the fourth day. The time-sharing tests, lasting about 30 minutes, consisted of 45 trials of fixed difficulty tracking in 3 blocks of 15 trials, 1 block for each of 3 levels of tracking test difficulty. Following the time-sharing tests each subject received 5 trials in critical tracking mode as a final test of tracking skill.

Data

The tester recorded the effective time delay score for each of the 40 initial and the 5 final trials of critical tracking. Recorded on a standard form specifically designed for use with critical tracking in the aviator selection research program, the critical tracking scores were later transcribed to standard 80 column computer card image forms, checked by a second person, and keypunched with verification. A special FORTRAN program was prepared to compute means and standard deviations for the 9 blocks of 5 trials and to compute the _z_-score conversion of the MSSD measure from all the data in the first 40 trials.

Design

A two-way categorization was used as the design of the subsequent analyses. The two categories were type of subject, trainee versus attritee, and type of performance, random (_z_-score less than 1.96) and nonrandom (_z_-score greater than or equal to 1.96); nonrandom in this case means that the data contained a linear or higher order polynomial trend.

Data Analysis

The first step in the data analysis was to compute a chi-square to test the hypothesis that frequency of classification of type of performance was not dependent on student category. Acceptance of this null hypothesis of no dependency would be used as evidence for employing a least squares analysis of variance procedure with the observed cell frequencies as the best estimates of the proportions in the population. Rejection of the null hypothesis of frequency of classification would indicate a need to employ methods to adjust the degrees of freedom in the analysis of variance procedures.

A 2 between-, 1 within-subjects repeated measures analysis of variance was used to test hypotheses about the equality of (a) mean effective time delay and (b) the standard deviation of effective time delay for the five trial blocks. Any effect in the chi-square test or the analyses of variance was considered statistically significant at the conventional .05 level.

RESULTS

The _z_-score transform from each subject's data was used to classify his/her performance as random or nonrandom. If the _z_-score was less than 1.96 the performance was classified as random. Any performance with a z-score greater than or equal to 1.96 was considered nonrandom, i.e., the data contained a trend. As a one-tailed test, this rule would result in a Type I classification error about 2.5% of the time. Table 2 gives the breakdown of number of subjects in each cell of the two by two student category by performance type matrix.

Table 2

Breakdown of Number of Subjects

Student Category	Type of Performance: Random	Nonrandom	Total
Trainee	11	9	20
Attritee	2	7	9
Total	13	16	29

A chi-square analysis was used to determine if the classification of random versus nonrandom performance was dependent on student category. The marginal totals were used to define the expected cell values because there was no prior reason to expect a particular breakdown pattern. The results of the chi-square analysis revealed no statistically significant dependency in the observed breakdown of number of subjects ($\chi^2 = 1.53$, $p > .10$, 1 df). This result was interpreted as evidence for using a least squares analysis of variance for unequal cell frequencies with mean effective time delay (Winer, 1971).

Mean Effective Time Delay

The measure of skill in the critical tracking test was effective time delay. Means for each subject for nine blocks of five trials in the 40 practice and 5 final test trials were analyzed with analysis of variance (Table 3). The hypothesis of an interaction between student category and type of performance across the nine blocks of five trials was not confirmed by the mean effective time delay measure. The analysis of variance revealed statistically significant main effect for blocks of trials which indicated that average performance had improved with practice (Figure 3).

There were two statistically significant interactions for the mean effective time delay. Student category interacted with blocks of trials

Table 3

Analysis of Variance Summary for
Block Means of Effective Time Delay

Source	df	Mean Square	F-Ratio	$\hat{\omega}^2$
Total	260	2696.22		
Between Subjects	28	12648.45		
Student Category (A)	1	5024.53	.43	-
Performance Type (B)	1	35276.90	2.96	.004
A x B	1	16242.16	1.36	.001
Error	25	11504.52		
Within Subjects	232	1495.09		
Blocks (C)	8	24921.2.	43.38***	.470
A x C	8	1513.15	2.63*	.023
B x C	8	2314.58	4.03**	.043
A x B x C	8	245.53	.43	-
Error	200	574.51		

*$p < .025$

**$p < .01$

***$p < .001$

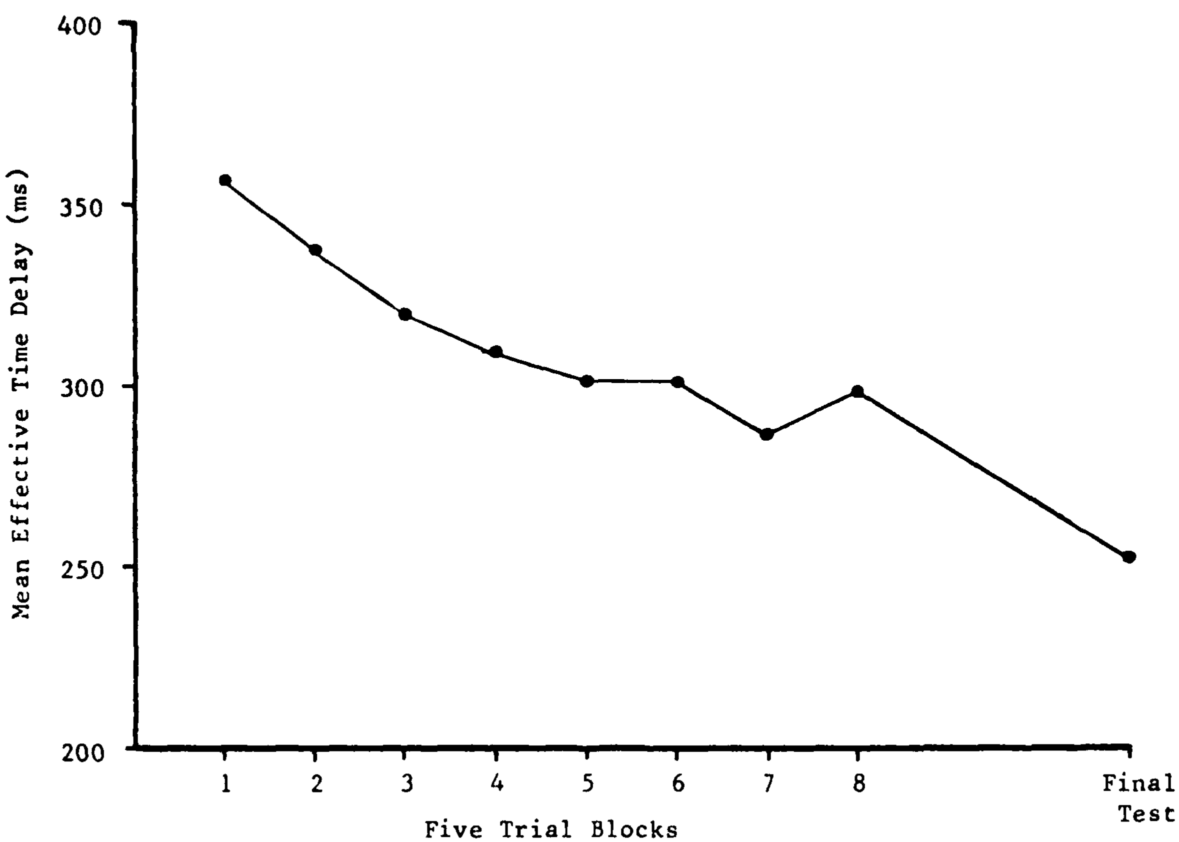

Figure 3: Improvement of mean effective time delay as a function of blocks of trials.

(F = 2.63, p < .025, df = 8, 200, proportion of variance = .023). As shown in Figure 4, the source of this interaction effect was the larger effective time delay means for the attritees on the first three blocks of trials. The other statistically significant interaction was type of performance with blocks of trials (F = 4.03, p < .001, df = 8,200, proportion of variance = .043). Figure 5 shows that the source of this effect was the difference in slopes between the two types of performance which indicates the greater rate of learning or degree of effort for the nonrandom group.

Variability of Performance

Analysis of the block standard deviations supported the hypothesis that a measure of variability of performance would be more sensitive to differences of degree of effort than a measure of central tendency. Analysis of variance with the block standard deviations confirmed the hypothesis that student category would interact with type of performance across the blocks of trials and also revealed other significant differences (Table 4). Figure 6 shows mean standard deviation as a function of student category and type of performance across blocks of trials. One striking feature of these plots is the extreme differences in block to block variability of the two attritee groups in relation to the variability of the trainees. The random trainee group exhibits the least block to block variability and the nonrandom trainee group gives strong evidence of improvement of variability with practice. Finally, the equivalence of the mean standard eviation on the final test for each of the four groups strongly suggests that factors other than differences in level of tracking skill are influencing the performances of the members of the different groups.

Some caution must be used in interpreting the variability of the random attritee group because the group has only two subjects. However, these two subjects also have the greatest total variances of any of the subjects in the design matrix (Table 5). As would be expected from an insection of the group plots in Figure 6, the size of the total variances in Table 5 is correlated with group membership. This correlation is supported by the significance of the between subjects effects in the analysis of variance summary (Table 4). Table 6 gives the mean standard deviations for each of the main effects and the interaction in the two by two student category by type of performance part of the design. Finally, Figure 7 shows the interaction of type of performance across blocks of trials on mean block standard deviation. The interesting feature of this interaction is the increasing variability trend of the random versus the decreasing variability trend of the nonrandom groups. This difference of trend of variability as a function of type of performance is strong support for the hypothesis that MSSD is an indicator of differences in performance patterns.

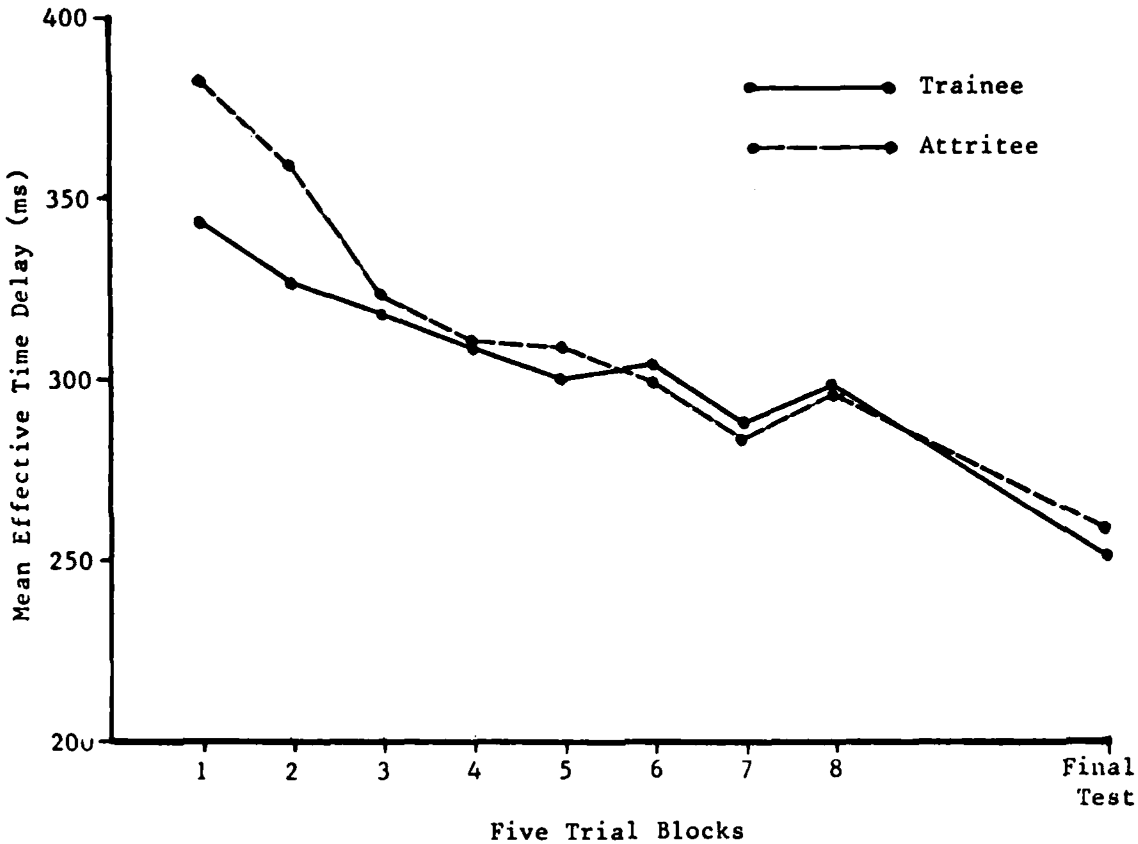

Figure 4: Interaction of Student Category on Mean Effective Time Delay Across Blocks of Five Trials

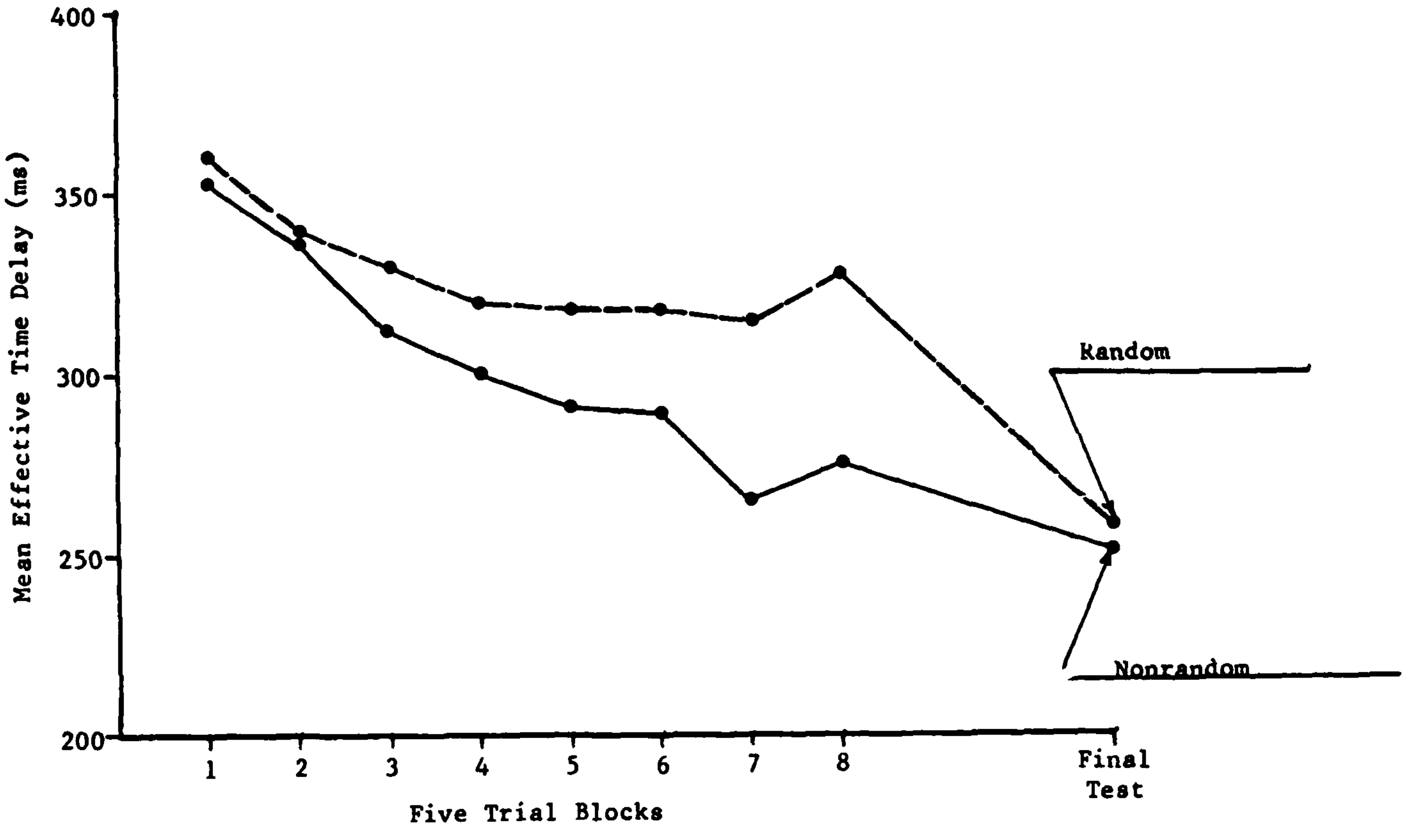

Figure 5: Interaction of type of performance across blocks of trials on mean effective time delay.

Table 4

Analysis of Variance Summary for
Block Standard Deviations of Effective Time Delay

Source	df	Mean Square	F-Ratio	$\hat{\omega}^2$
Total	260	308.54		
Between Subjects	28	420.86		
Student Category (A)	1	1734.88	6.53**	.018
Performance Type (B)	1	1193.61	4.49*	.011
A x B	1	2213.94	8.33***	.024
Error	25	265.67		
Within Subjects	232	294.67		
Blocks (C)	8	385.25	1.48	.012
A x C	8	201.35	.77	-
B x C	8	524.14	2.01*	.026
A x B x C	8	935.17	3.59***	.067
Error	200	260.34		

*p <.05

**p <.025

***p <.001

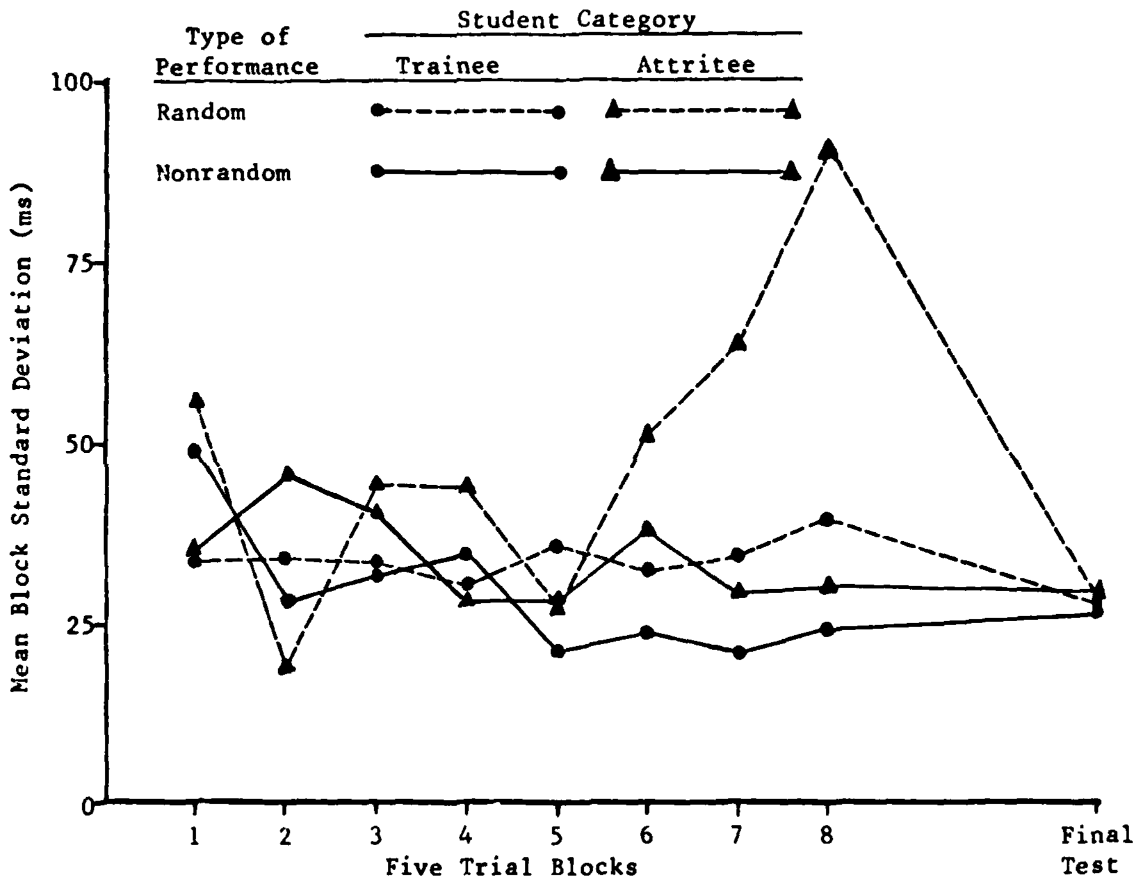

Figure 6: Interaction of student category with type of performance across blocks of trials on mean block standard deviation.

Table 5

Sum of Block Variances for each Subject

Student Category	Type of Performance: Random	Type of Performance: Nonrandom
Trainee	6509.8	4890.5
	6850.4	5519.7
	7570.0	6520.2
	10040.3	8010.5
	10903.3	8649.5
	11549.0	9439.6
	12211.4	12700.4
	14599.8	15989.9
	17152.5	18569.7
	18239.4	
	19180.8	
Attritee	21580.9	8309.4
	29657.8	9499.5
		11220.6
		13429.4
		14869.6
		16350.1
		18228.8

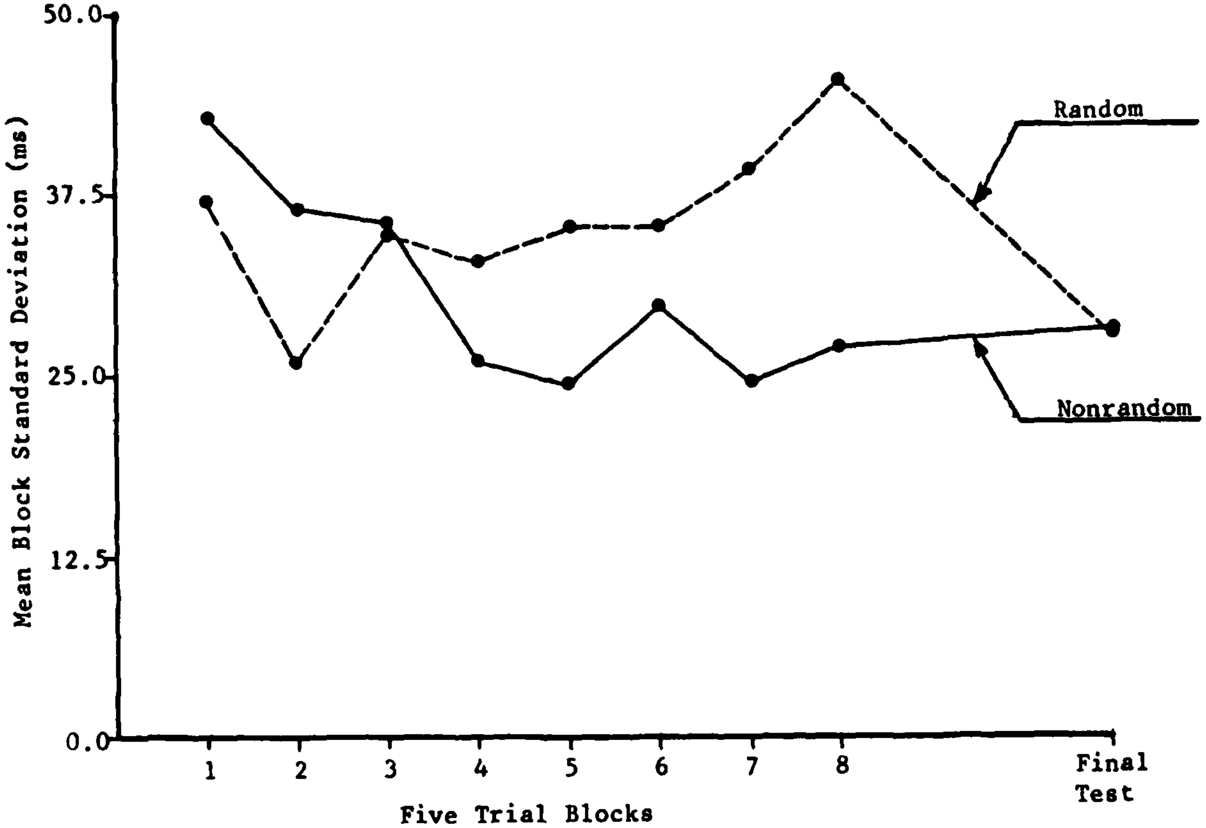

Figure 7: Interaction of type of performance across blocks of trials on mean block standard deviation.

Table 6

Mean Block Standard Deviations for Student

Category by Type of Performance

Student Category	Type of Performance: Random	Nonrandom	Combined
Trainee	33.39	29.16	31.49
Attritee	47.68	34.03	37.06
Combined	35.59	31.29	33.22

DISCUSSION

The main hypothesis of this investigation was that degree of effort would be a source of confounding in tracking test performance. The results confirmed this hypothesis if degree of effort varies with motivation to perform and differences in motivation depend on student category. The major source of this confounding was differences in variability of performance as a function of number of test trials. The source of the interaction is most clearly apparent in the comparison of type of performance with student category across the blocks of trials on mean block standard deviation (Figure 6). Inspection of mean effective time delay interactions shows that mean effective time delay is correlated with variability of performance which is consistent with Poulton's hypothesis of a shift in performance strategy.

A second hypothesis was that inadequate practice was a source of confounding in the measurement of level of achievement in previous research. In this investigation, level of achievement is represented by mean effective time delay and Figure 3 clearly shows a large improvement of this measure, even after the eighth trial block. A comparison of mean effective time delay from this investigation and a previous study by Pew et al. (1977) with the same tracking test further supports the hypothesis of inadequate practice. In the Pew et al. study 92 students in Air Force Undergraduate Pilot Training at Williams Air Force Base, AZ, performed 10 trials of the critical tracking test. Table 7 is a comparison of the mean and standard deviation of effective time delay for the last 7 trials of the Pew et al. study with the means and standard deviations of 5 trials blocks and the final test for trainees in the present study. (Trainees were used for comparability of populations.) The important comparisons in Table 7 show that there were no significant differences between the Pew et al. results and those of this investigation on the first 4 blocks of trials.

Table 7

Means and Standard Deviations of Effective Time Delay from Pew et al. (1977) and Blocks of Trials for Trainees from the Present Investigation

Measure	Pew et al.[a]	Block[b] 1	2	3	4	5	6	7	8	Final Test
Mean	340.3	344.0	327.6	318.5	308.5	300.0*	303.1*	288.7*	298.9*	250.9**
S.D.	52.3	66.3	59.4	59.4	58.2	55.3	54.1	58.4	60.1	40.0

[a] $\underline{n} = 92$; [b] $\underline{n} = 20$; $*\underline{p} < .05$; $**\underline{p} < .001$

The results of this investigation indicate that mean square successive differences (MSSD) should be a useful statistical tool in subsequent research. Although MSSD was employed in the present investigation as a one-tailed test to indicate polynomial trends, significant negative values of the $\underline{z}$-score derived from MSSD would indicate that the data contained systematic cyclic or periodic trends, i.e., trends describable with trigonometric functions. This latter feature makes MSSD especially useful in the analysis of tracking performance from continuous control tasks where periodic features of the data may indicate important differences in operator control behaviors. With a significant positive or negative $\underline{z}$-score from the MSSD measure, the data analyst is justified in a detailed search for the sources of the specific polynomial or periodic trends in an individual set of data.

Research is needed to establish the predictive validity of differences in patterns of performance from the tracking test for overall success in pilot training. Interviews with instructor pilots have indicated that lack of motivation is frequently a source of inadequate student progress in Army helicopter pilot training. This instructor pilot observation is supported by two sources of additional evidence. First, some 50% of all attrition in the Army helicopter pilot training program results from resignations (Elliot & Joyce, 1978). Furthermore, motivation was identified as a major factor among resigning students. Second, an unreported exploratory investigation at the US Army Aviation Center found a correlation of .78 between instructor pilot ratings of basic student pilot qualities, e.g., motivation, judgment and the like, on daily grade sheets from early primary training and subsequent eliminations from advanced training. This evidence suggests that the present approach may yield a substantial reduction in the residual variance of the aviator trainee selection testing process.

The approach used in this investigation also presents some interesting possibilities for further research in aviator trainee selection and management methods. For example, detailed analyses of individual performance trends were not accomplished in the present investigation. However, the logical analysis of degree of effort depicted in Figure 1 indicates that differences in such trends should further differentiate among types of performance and the associated performance strategies. One interesting hypothesis is that learning behavior, i.e., performance strategy, in a simple tracking test would predict learning behavior in more complicated tasks, i.e., performance in aircraft control.

Cronbach and Snow (1977) evaluate the hypothesis of prediction from learning behavior in these terms:

> If individual differences prove to be stable and predictable, one can capitalize on findings from the experiment in which learning is observed only for a short time, perhaps on just one task or topic. If individual differences are radically altered during learning... the short-term experiments...will not give practically useful conclusions. Under this hypothesis, persons who learn most efficiently, among a group all of whom have become familiar with the problem, would not generally be the ones who learned most efficiently at the outset; hence, they would not have been among the most successful learners in a short experiment (p. 126).

The major issue is whether attitudinal differences such as motivation which are reflected in the degree of effort measurement procedures are relatively stable characteristics of an individual's learning behavior. As a test of the Cronbach et al. hypothesis in a subsequent investigation, the methods of this investigation will be employed to predict performances of these same subjects in fixed stability tracking, time-sharing, and a job-sample test administered on the UH-1 flight simulator.

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